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## REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED			1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY N/A since Unclassified			3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.	
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE N/A since Unclassified				
4. PERFORMING ORGANIZATION REPORT NUMBER(S) FR-31			5. MONITORING ORGANIZATION REPORT NUMBER(S) DNA-TR-87-84	
6a. NAME OF PERFORMING ORGANIZATION Ford Laboratories, Inc.		6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Director Defense Nuclear Agency	
6c. ADDRESS (City, State, and ZIP Code) 6908 A Sierra Court Dublin, California 94568			7b. ADDRESS (City, State, and ZIP Code) Washington, DC 20305-1000	
8a. NAME OF FUNDING / SPONSORING ORGANIZATION		8b. OFFICE SYMBOL (If applicable) TDTD/Corseth	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DNA 001-84-C-0112	
8c. ADDRESS (City, State, and ZIP Code)			10. SOURCE OF FUNDING NUMBERS	
			PROGRAM ELEMENT NO 62715H	PROJECT NO J11AMXJ
11. TITLE (Include Security Classification) DESIGN & DEVELOPMENT OF AN INERTIAL FRAME DISPLACEMENT GAUGE				
12. PERSONAL AUTHOR(S) Ford, F. C.; Vincent, C. T.; Gaines, T.; and Franzen, R.				
13a. TYPE OF REPORT Technical		13b. TIME COVERED FROM 840101 TO 841101		14. DATE OF REPORT (Year, Month, Day) 870304
15. PAGE COUNT 26				
16. SUPPLEMENTARY NOTATION This work was sponsored by the Defense Nuclear Agency under RDT&E RMSS Code B345084466 J11AMXJD00038 H2590D.				
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) Stress Gauges Laboratory Techniques Nuclear Explosions Displacement	
FIELD	GROUP	SUB-GROUP		
14	2			
18	3			
19. ABSTRACT (Continue on reverse if necessary and identify by block number)  The mechanical and electrical design features of a new type displacement gauge are discussed. Results of laboratory testing and data reduction techniques are discussed in detail. The gauge concept is based on inertial frame approach utilizing a dropped weight at an appropriate time during an explosive or nuclear event to measure displacement.				
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT <input type="checkbox"/> UNCLASSIFIED/UNLIMITED <input checked="" type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED	
22a. NAME OF RESPONSIBLE INDIVIDUAL Sandra E. Young			22b. TELEPHONE (Include Area Code) (202) 325-7042	22c. OFFICE SYMBOL DNA/CSTI

DD FORM 1473, 84 MAR

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# **DESIGN AND DEVELOPMENT OF AN INERTIAL FRAME DISPLACEMENT GAUGE**

F. C. Ford, et al.

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Dublin, CA 94568

4 March 1987

Technical Report

CONTRACT No. DNA 001-84-C-0112

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## Preface

This report concludes the gauge development research begun in January 1984 and completed in August 1984, under the sponsorship of the Defense Nuclear Agency. Ford Laboratories, Inc., acknowledges the early support and encouragement of M. Frankel and G. Ullrich of DNA. Helpful discussions were also held with W. Davis and J. Ingram of Waterways Experiment Station.

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## SECTION 1

### INTRODUCTION

This report summarizes the design effort, experiments and analysis undertaken in support of Ford Laboratories, Inc. effort to develop a new type displacement gauge under Contract DNA-001-84-0112. The work covered a period of six months from January through June, 1984. Only laboratory tests were undertaken in this phase of the program.

It was the objective of the work reported herein to avoid the usual complications and uncertainties associated with displacements determined from integrated acceleration measurements. The approach was to use an inertial frame type gauge with a freely dropping weight. The dropped weight would permit instantaneous measurement of displacement while falling after release by inducing measurable capacitance changes between the dropped weight and the gauge canister assembly. Use of an inert ball, rather than a transmitter, would permit use of a smaller dropped weight as well as permit multiple drops for pretest calibration runs after gauge emplacement at time of event without changing the gauge emplacement conditions.

The results, while complicated in terms of simple calculations, support the conclusion that this dropped weight inertial frame gauge permits the position of the ball to be determined at all points and times during its free fall condition. Use of a small ball and a relatively large canister permit rather large (10cm) dynamic displacements to be measured.

## SECTION 2

### BACKGROUND

Direct measurement of displacements produced by buried explosive charges are a key factor for determining materials properties needed for ground motion prediction calculations for near surface nuclear bursts. Previously, displacements have been measured by integrating the output of accelerometers and/or special velocity gauges. The transducers used in such devices often experience depolarization, tilting, baseline shifts, or other mechanical/electrical phenomena during shock onset. Corrections are generally introduced into measured results to account for base line shift, noise and/or failure of the gauge to return to zero after a reasonable time.

In principle, a simple dropped weight system could be developed to measure horizontal radial permanent displacement only. The ball is released prior to arrival of any ground motion and falls freely while the canister is displaced by subsequent shock arrival. Knowledge of the release point, release time and determination of the impact point and time would allow measurement of the permanent displacement. The canister floor could be divided into a grid arrangement which would permit rapid and accurate readout of the coordinates of the impact point. This simple concept has been extended in the Ford Laboratories gauge by measuring time dependent capacitance values of the ball and the side walls, top and bottom of the canister as well as coordinates and time of impact. Figure 1 shows the Ford Laboratories gauge concept in some detail.

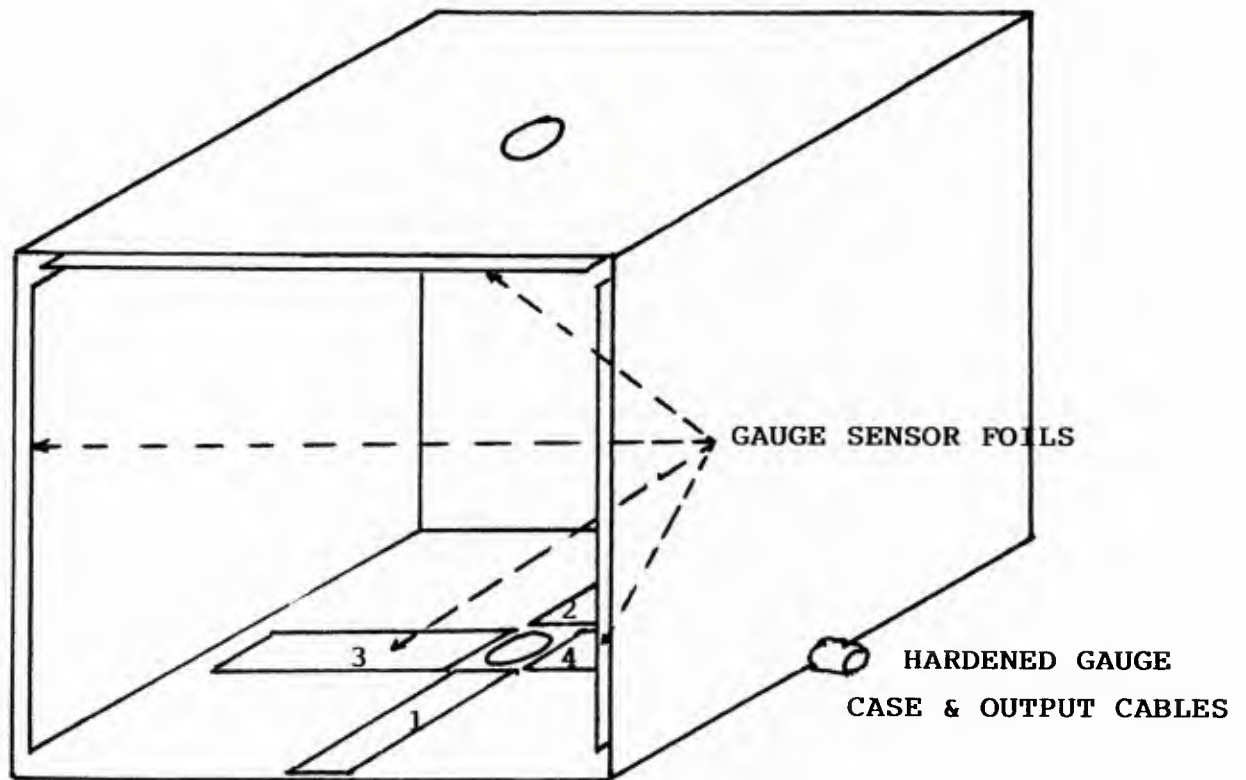


Figure 1. Basic gauge concept

In this schematic the essential features of the gauge are shown. The sensor foils are isolated from each other and from the gauge case. The bottom sensors are designed to provide front-to-rear and left-to-right pairs (1 & 2 are front-to-rear- while 3 & 4 are left-to-right sensors). Differential capacitance measurements of sensor pairs permits determination of the drop weight path during events. The gauge dimensions should be selected to provide the ranges required for displacements from a given event as proper gauge size increases resolution of drop weight position. Shown are the entrance and exit holes for the drop weight. Not shown are the release mechanism, the connecting cables or the electronics for the gauge readouts.

### SECTION 3

#### EXPERIMENTAL APPARATUS & RESULTS

A particularly difficult task is the selection of an efficient geometric and electrical configuration for the capacitance sensors. First trials consisted of simple sensing foils isolated from each face of the canister including top and bottom. Figure 2 shows the recorded capacitance changes during the drop time including the "bounce" of the ball. Subsequently these simple sensing foils were divided into strips to permit more accurate measurement of ball position during the free fall period. Calibration and testing of the many conceivable configurations of foil arrangements was not possible in this program. To detect the two horizontal displacements as well as the vertical position of the dropped weight configuration, four strip pickups were introduced at the bottom of the cavity - two each for each dimension, each pair connected to a differential capacitance measurement circuit as shown in Figure 3. The top of the cavity remained a single foil at a static potential of + 300V with respect to the other foils. While the tests and evaluations of signals generated were difficult and lengthy several series of static drops along various drop paths were performed. A somewhat simplified description of the results is given to better promote an understanding of how the gauge should work.

A number of vertical drops were recorded for each of the 25 locations indicated in Figure 4. Measurement of capacitance changes for right to left and front to rear foils were made for all drops. The measurements from "repeated" drops confirmed the reproducibility of the measurements. Measurements along various lines such as A, B, or C in Figure 5 varied strongly in the right to left differential but not in the front to rear differential. Correspondingly, measurements along D, E, and F varied strongly in front to rear differential, but not in the right to left differential. These data, after suitable normalization, are shown for comparison in Figure 6 for lines A, B, & C. Similar results were obtained for D, E, & F. It is clear from these plots that using two static drop traces one can

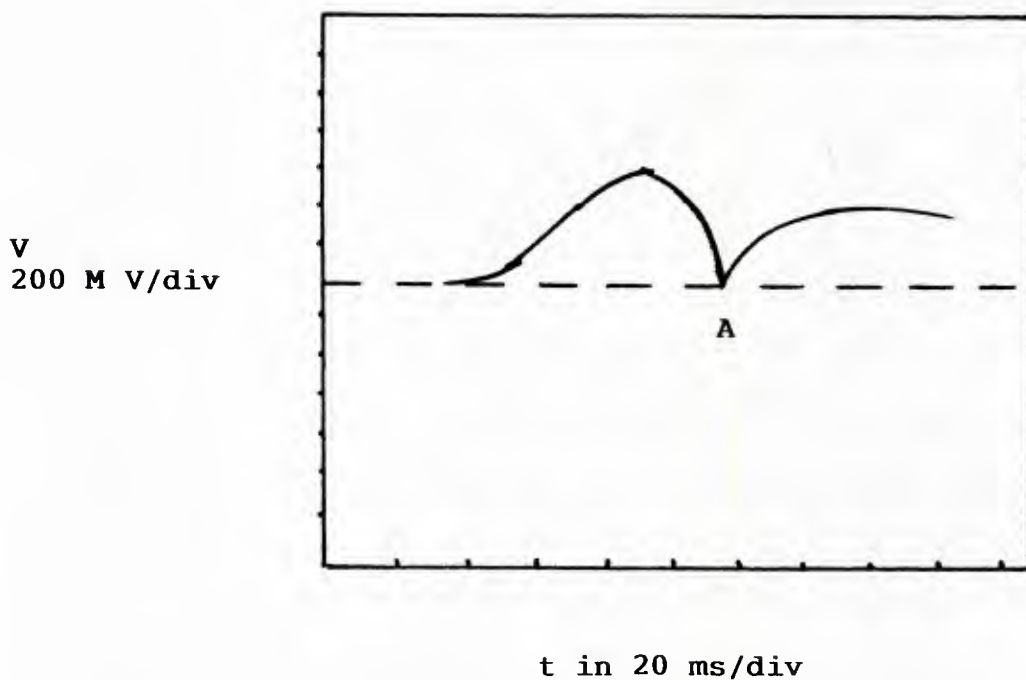


Figure 2. Measured capacitance change during drop.

Measured capacitance change during test drop in gauge. Time measured to point A corresponds to transit time of the weight from release at the top to arrival at the bottom of the gauge. Pt A in this figure actually represents the time of bounce at the bottom and the continuation of the signal beyond pt A indicates the motion of the bouncing weight.

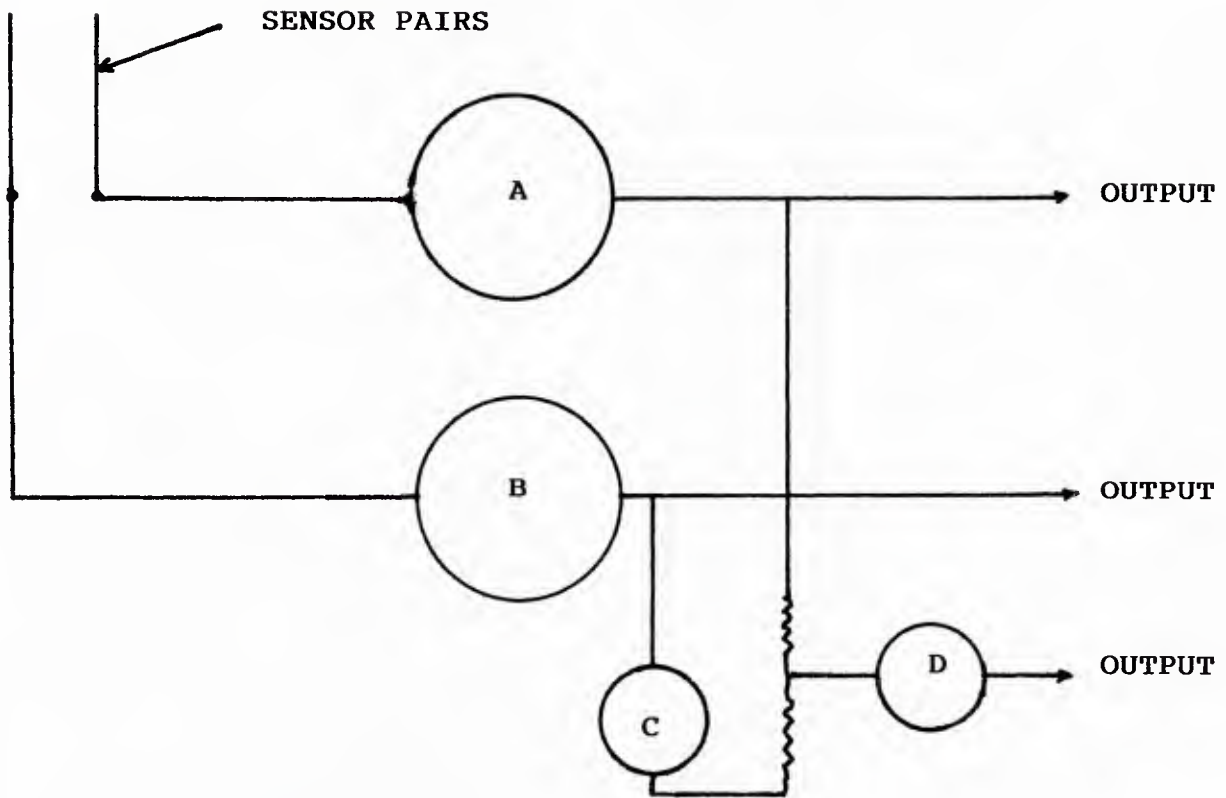


Figure 3. Typical detection circuit for differential capacitance.

Sensor pairs are connected to amplifiers A & B with gains ranging from 40 to 200. Outputs of these amplifiers, as shown, were monitored individually and with the use of the C inverter were subtracted electronically and the differential sensed through output D. The sensor pairs were typically biased to 300 volt  $\pm$  D.C. charge during tests. Sensitivity was such that for a 10 cm x 10 cm case the differential output capacitance voltage was as large as 450 mv. In final calibrations only the top sensor and bottom sensor pairs were needed to accurately determine the drop weight position in time.

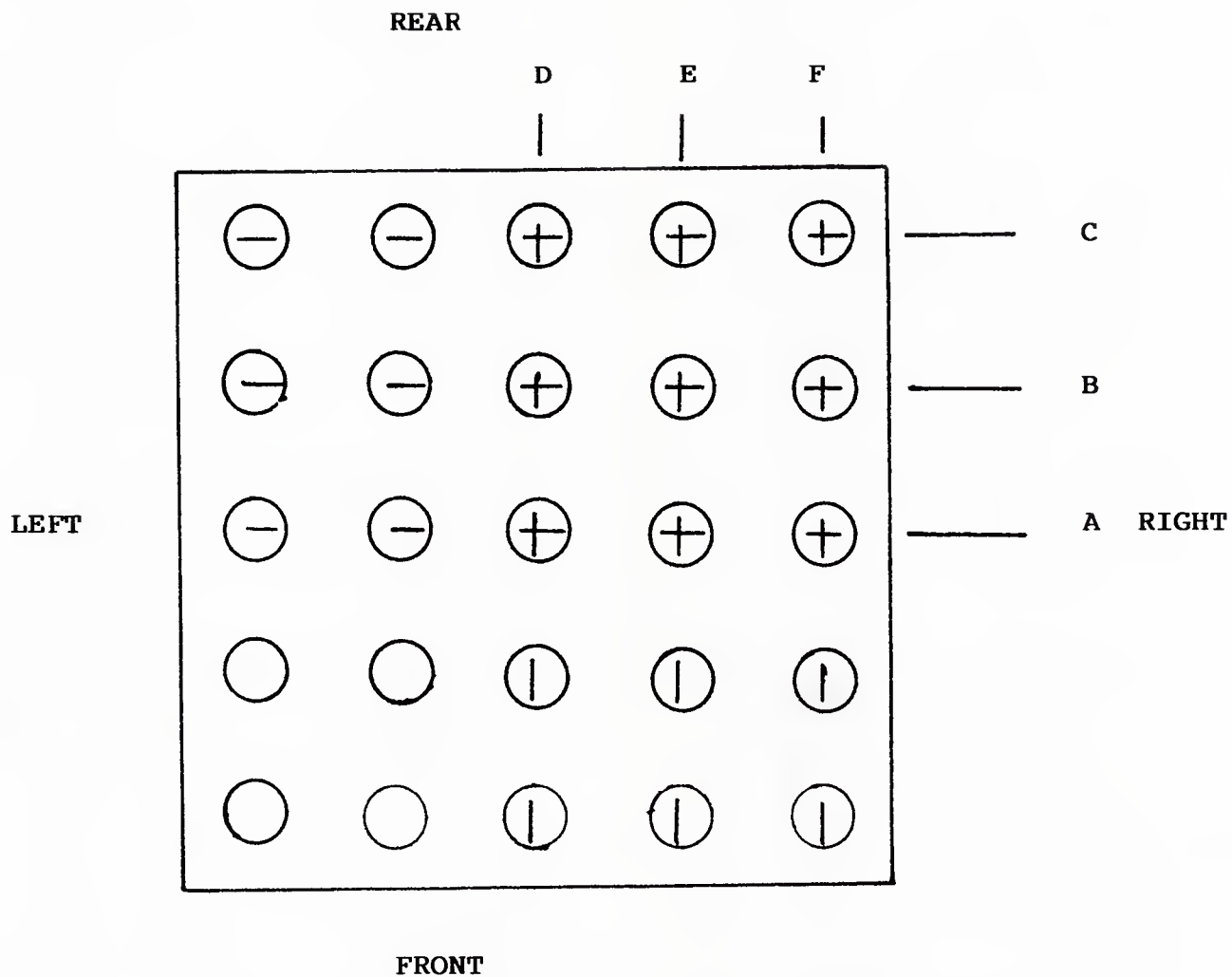


Figure 4. Top calibration test plate.

Calibration test drops were made through a special top plate with the 5 x 5 matrix of drop holes as shown. Lines A & D went through the center drop hole while lines B and C and E and F were off axis as shown. Quadrants to the left of the line D turned out to be mirror images of the quadrants to the right as symmetry was preserved. Plots of the drop signals for key locations are shown in Figure 5.

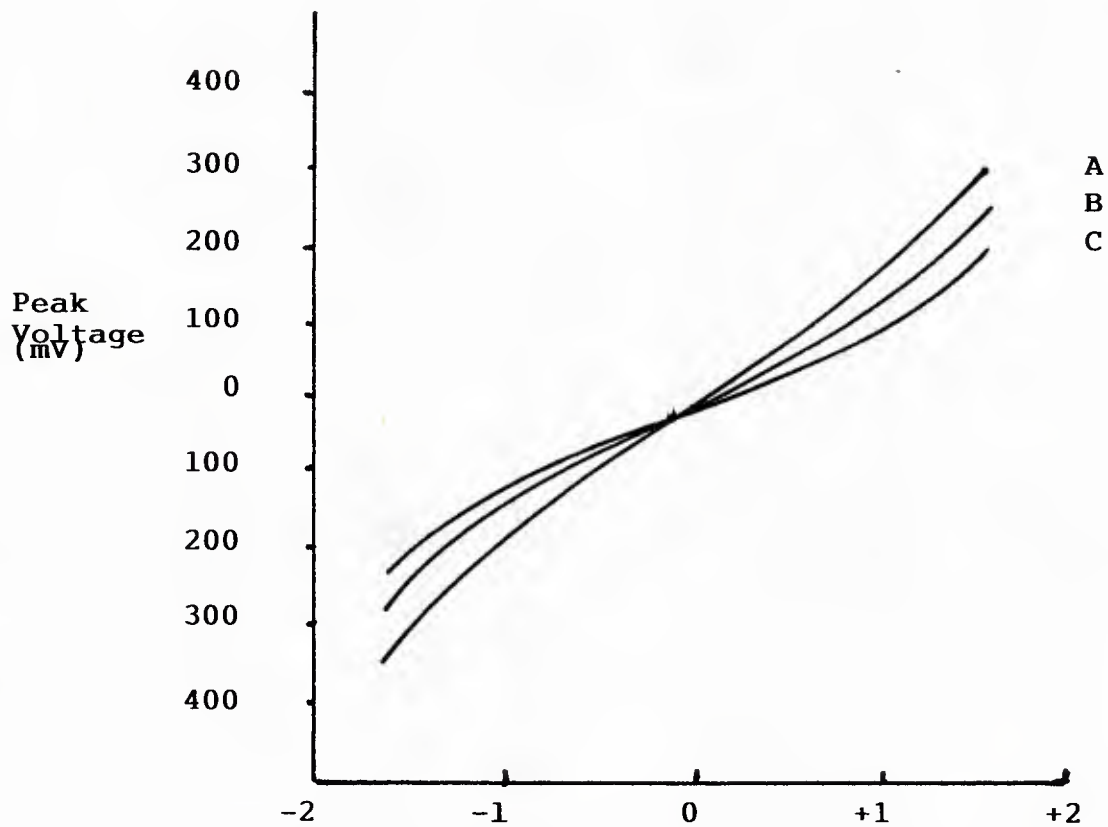


Figure 5. Distance from center line (inches).  
(right-left dimension)

Form of Peak Differential Voltage for Right-to-left Position signals along lines A, B, C for three front-to-rear locations. Similar signal curves were developed for D, E, F lines and left-to-right locations.

determine the drop location coordinates in a horizontal plane from the peak values of the traces.

There is a small region near the beginning of the drop where spatial resolution is insufficient. Figures 6 & 7 shows signals vs. drop height and time with one vertical line shown for a specific height. A voltage-vs.-distance from center line curve for each H of interest can be plotted as is shown in Figure 8 for an H of 1.5 inch. The result is that the drop weight location H for a given time t for a dynamic drop event has been determined from three measurements of voltage. From a complete set of calibration curves these data can be translated into the two horizontal coordinates at time t. As a practical matter, these data reductions and evaluations would be performed by fairly simple computer programs rather than the graphics approach used here.

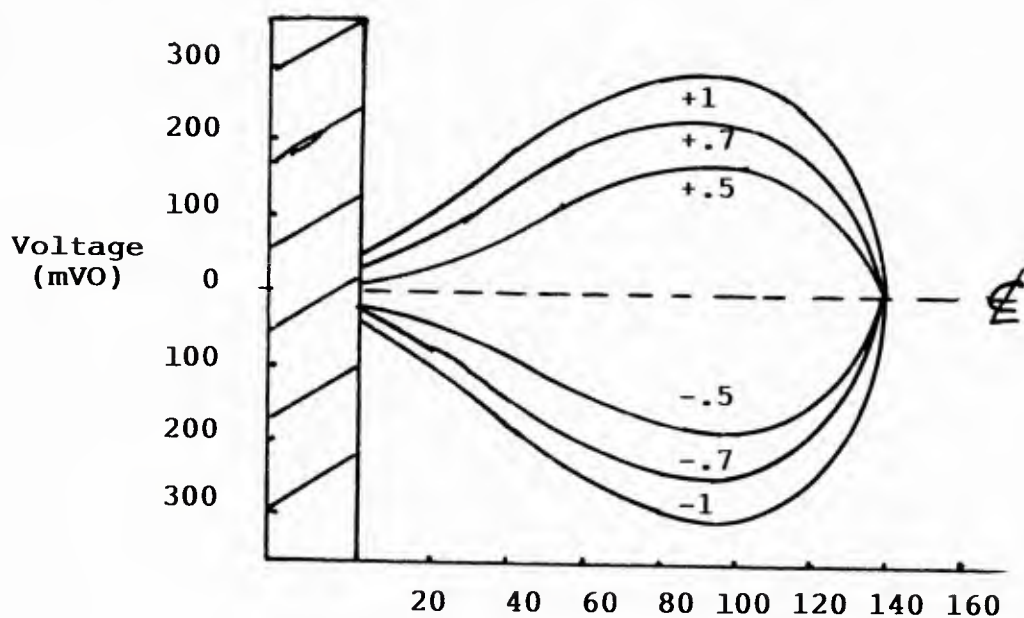


Figure 6. Drop time (ms).

Form of signals for drops on E line at three different distances from center-line vs. drop time  $\pm 1$  inch,  $\pm .7$  inch,  $\pm .5$  inch. The shaded area is the region of poor resolution in space.

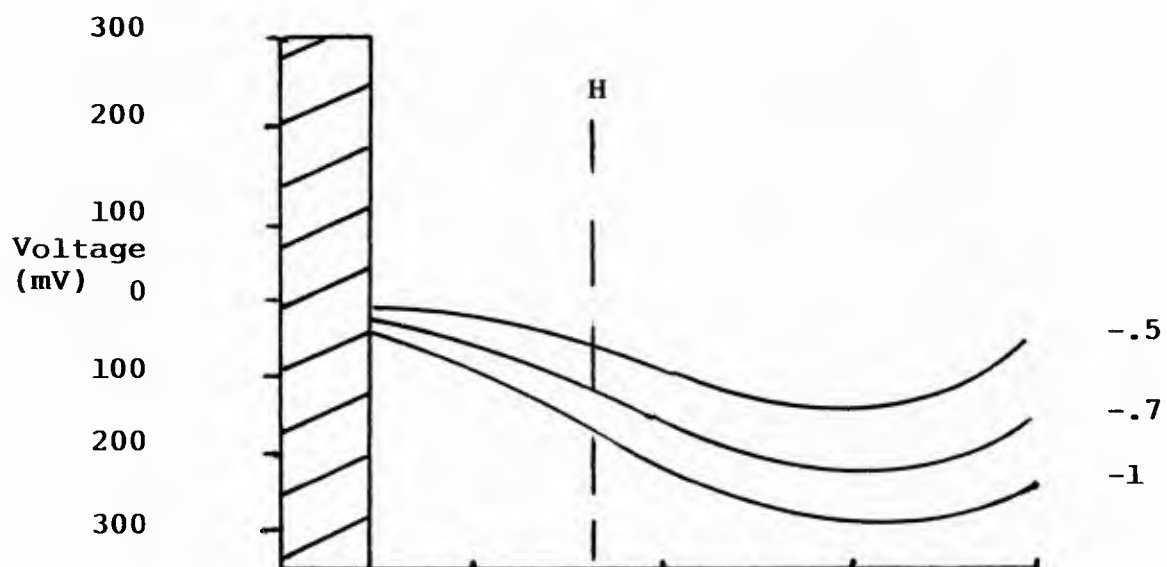


Figure 7. Drop height - inches.

Form of signals generated over drop height (modified form of figure above). A given height line H is shown, for reference, indicating signal variation at that position.

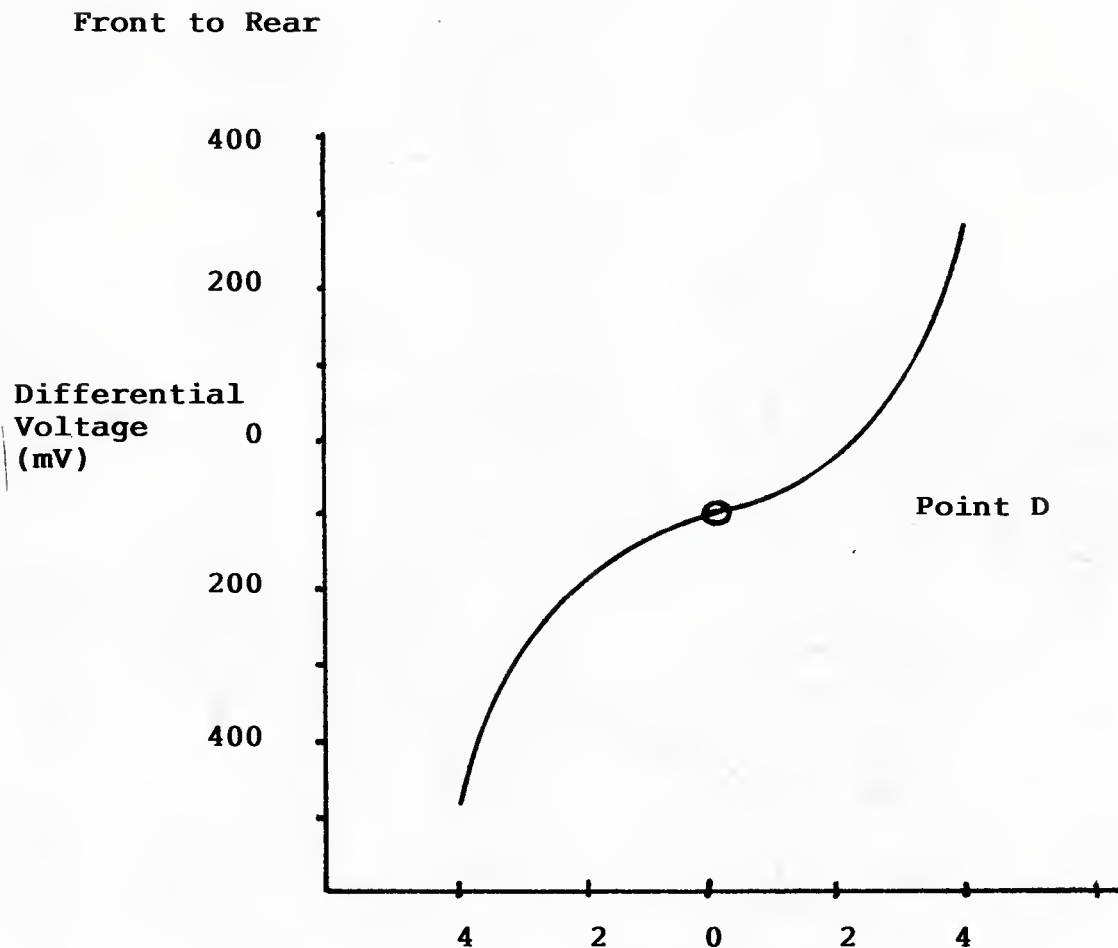


Figure 8. Front-to-rear distance from centerline (inches).

Front-to-rear differential voltage vs. distance from center line for a given drop height (see text for discussion).

## SECTION 4

### CONCLUSIONS

The achievements during the six months development effort include:

1. An overall design concept has been developed to permit displacement measurements with an inertial frame type gauge.
2. Electronic circuitry has been designed and tested which senses and amplifies the small capacitance changes introduced by a dropped weight.
3. A prototype gauge has been designed and fabricated which incorporates a release mechanism for multiple drops, a drop weight receptacle to remove used drop weights, shielded ducting for leads to connect to location sensors, a simple constant static voltage charge means for the top element, and a sturdy durable case needed for soil emplacement during testing.
4. Laboratory testing and calibration which have led to improved sensor element design and configurations.
5. Methods of data interpretation which show the reproducibility and accuracy of reconstruction of time dependent three dimensional paths of the drop weight from the sensor signals and calibration data.

The gauge, and measurements with the gauge, require careful calibration. The measurement of position with this method is non-linear requiring large amounts of calibration data to be evaluated and stored for computational reduction of actual signals from an event. Numerical interpretation needed for data reduction is difficult for non-linear signals developed by the gauge. Loss of any of the three required traces makes for insufficient resolution and data

reduction is next to impossible. Loss of the vertical signal renders the horizontal records useless. In spite of these considerations, the gauge shows promise in laboratory calibration and testing. Repetitive drops show reproducible data. Fixed location measurements of the ball can be quickly confirmed by the data reduction process. While field testing would impose additional constraints and conditions related to data collection (noise, cable malfunctions, gauge tilting, etc.), the gauge could easily be made ready for a field testing program.

Remaining to be done to make the gauge field ready are the following tasks:

1. Fabricate a prototype gauge with a drop weight diameter of 0.5" and case dimensions of at least 10 x 10 x 10 cms.
2. Complete a static and dynamic gauge calibration with denser drop grid locations and well defined displacement history.
3. Develop the microcomputer program for data reduction.
4. Shock and vibration harden the electronic elements of the gauge.
5. Simplify signal conditioning circuitry.

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